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A MOVING BED DRIER FOR COTTON RESEARCH

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INTRODUCTION

The shelf-type drier has been used in almost all of the qualitative and quantitative drying studies carried out at the Cotton Ginning Research Laboratory since its beginning in 1931. Occasionally, drying tests have been run using a batch-type screen-box drier. However, these driers do not readily lend themselves to adequate investigation of the several parameters that affect drying processes because airflow and exposure period of seed cotton to heated air are not widely variable. Further, an undesirable temperature gradient is associated with the tower drier system.

Accordingly, in order to achieve greater flexibility in designing cotton-drying experiments for determining optimum heat use, a different type of drier was required.

DESIGN OF THE DRIER

During the spring and summer of 1963, a moving bed, wire belt drier was designed and constructed with airflow so arranged that there was virtually no temperature gradient from cotton inlet to cotton outlet (fig. 1).

Means were provided for controlling the drying factors under study: (1) Air-to-cotton mass ratio was controlled by varying airflow through drier; (2) temperature was controlled by burner adjustment; and (3) exposure period was controlled by varying the linear speed of the horizontal conveying belt. Airflow restrictors of perforated metal in the heated air intake and exhaust sections gave even distribution of air.

The seed cotton batt was deposited on the moving horizontal belt at such a rate that heated air could pass through the batt and around individual cotton locks. Glass windows permitted continuous observation of the cotton in the drier (fig. 2).

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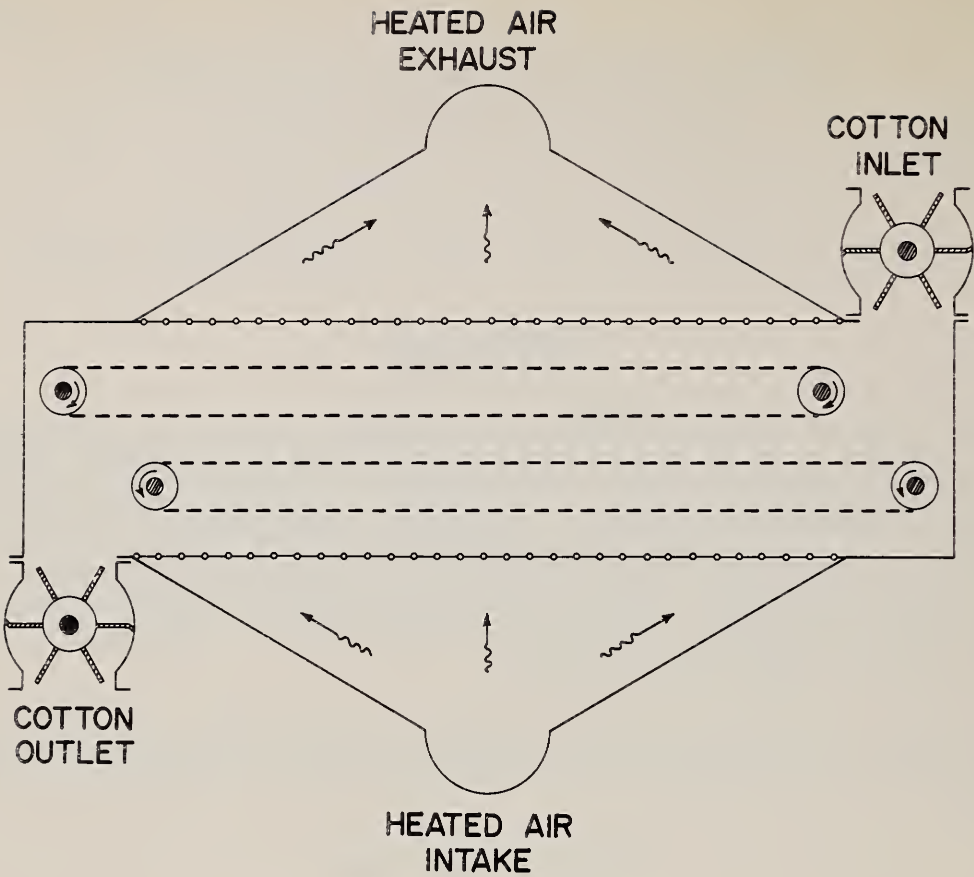

Figure 1. Cross-section drawing of the experimental moving bed drier.

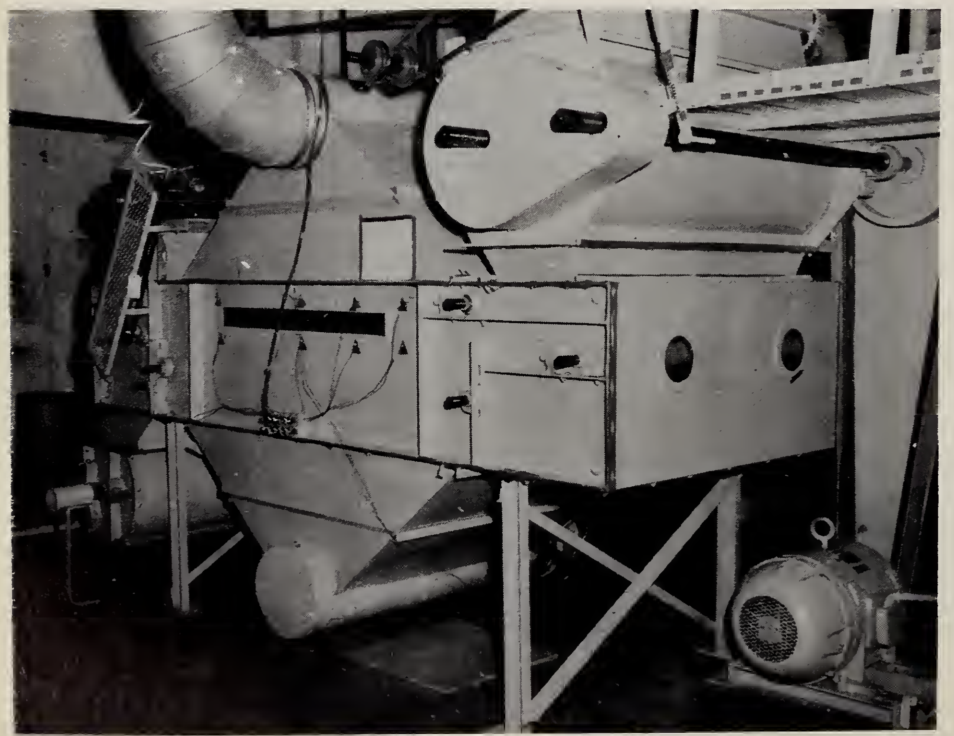

Figure 2. Moving bed drier showing thermocouple locations, variable speed motor for control of belt speed at rear top, and window for observing seed cotton batt.

Automatic temperature recorders showed that the heated air temperature at the approach side of the batt varied approximately 5 degrees along the cross section with a 10-degree drop across the seed cotton batt. In all, drying air temperatures at 12 locations were continuously recorded. Air/cotton mass ratio was calculated using pitot tube airflow measurements.

LABORATORY EXPERIMENTS

Four hundred and ninety-five seed cotton lots of 15 to 30 pounds each were processed during 1963, 1964, and 1965 for examination of the following pertinent drying parameters: (1) Initial fiber moisture content, (2) air/cotton mass ratio, (3) exposure period, and (4) drying air temperature.

All drying-factor evaluation experiments included a common drying setup for studying possible interaction between factors. For example, all studies of the four factors included a lot dried with a 4.76 air/cotton mass ratio, air temperature of 230° F., and 15 seconds of exposure.

All lots were sampled for moisture content before and after drying. The samples were ginned on a 20-saw gin and the ginned lint was subsampled for oven moisture determinations.

Experimental data were analyzed to ascertain the effect of the four factors on rate of moisture removal and to relate these factors to the most efficient use of heat energy.

Heat energy was calculated in terms of B.t.u. per pound of seed cotton for each of the air/cotton mass ratios, temperatures, and exposure periods. It was calculated as an enthalpy function using the equation:

$$H = mh,$$

where H = the enthalpy of a system of mass m
m = mass of the air in the system per pound of seed cotton in the system
h = enthalpy per unit of mass in B.t.u. per pound

Initial Moisture

When the final moisture content and the quantity of moisture evaporated were examined with respect to the initial moisture content and exposure period, the drying rate was found to be greatest for the higher initial-moisture cottons, and, therefore, the heat-utilization factor was greatest for these cottons (table 1). These data show the final moisture content to be approximately linear with time.

Table 1. Effect of initial moisture content on final moisture and heat use, 1964 crop[1/]

Exposure time (seconds)	Moisture content after drying; initial moisture--			Moisture evaporated per 1,000 B.t.u. enthalpy; initial moisture--		
	13.3 pct.	9.9 pct.	6.6 pct.	13.3 pct.	9.9 pct.	6.6 pct.
	Percent	Percent	Percent	Lb. x 10^{-2}	Lb. x 10^{-2}	Lb. x 10^{-2}
5	12.4	9.4	6.4	28.8	23.8	19.5
10	12.0	8.9	6.1	20.3	21.3	18.3
15	11.5	8.7	5.8	18.5	17.6	14.2
Average	12.0	9.0	6.1	22.5	20.9	17.3

1/ Data are averages of nine experimental lots, involving drying temperatures of 160°, 230°, 300° F., and drier air volumes of 208, 761, 1467 c.f.m.

Air/Cotton Mass Ratio

Because air was not required for conveying cotton through the drier (in conventional tower driers, air is used to convey cotton as well as to serve as the drying medium), it was possible to use very low air volumes and consequently to obtain very low air/cotton mass ratios.

Although the data showed but little change in final moisture content at any of the three exposure periods used when the air/cotton mass ratio changed by factors of 3.6 and 7.0, the heat-use factor was lowered considerably (table 2). The implication is that maximum heat use occurs when the airflow rate is just sufficient to keep the drying surface temperature at the desired level.

Temperature

Drying temperature effects were investigated in 50-degree steps from ambient to 450° F. As drying air temperature increased, the fiber moisture content decreased steadily, and under the conditions of the experiments the relation of fiber moisture content to drying air temperature was found to be linear (fig. 3). The experiments showed that heat was used more efficiently on the higher moisture cotton. Plots of heat utilization vs. temperature show flattening of the curves as temperature increases (fig. 4). The flattening is a manifestation of the falling-rate phenomenon caused by depletion of moisture at relatively long drying periods.

Table 2. The effect of air/cotton mass ratio on final fiber moisture content and heat utilization, 1964 crop[1/]

Exposure period (seconds)	Air/cotton mass ratio		Final fiber moisture	Moisture evaporated per 1,000 B.t.u. enthalpy	
	Experimental	Change		Experimental	Change
	Lb./lb.	Factor	Pct.	Lb. x 10^{-2}	Factor
5	0.43	--	9.1	45.9	--
5	1.59	3.7	8.8	17.5	0.38
5	3.06	7.1	8.4	14.5	.32
10	.87	--	8.8	33.5	--
10	3.17	3.6	8.4	16.5	.49
10	6.11	7.0	7.9	12.1	.36
15	1.30	--	8.4	35.1	--
15	4.76	3.7	8.3	11.4	.32
15	9.17	7.0	7.5	10.9	.31

1/ Each datum is an average of 12 experimental lots consisting of air temperatures of 160°, 230°, and 300° F. and initial fiber moisture contents of 13.3, 9.9, 7.3, and 6.6 percent.

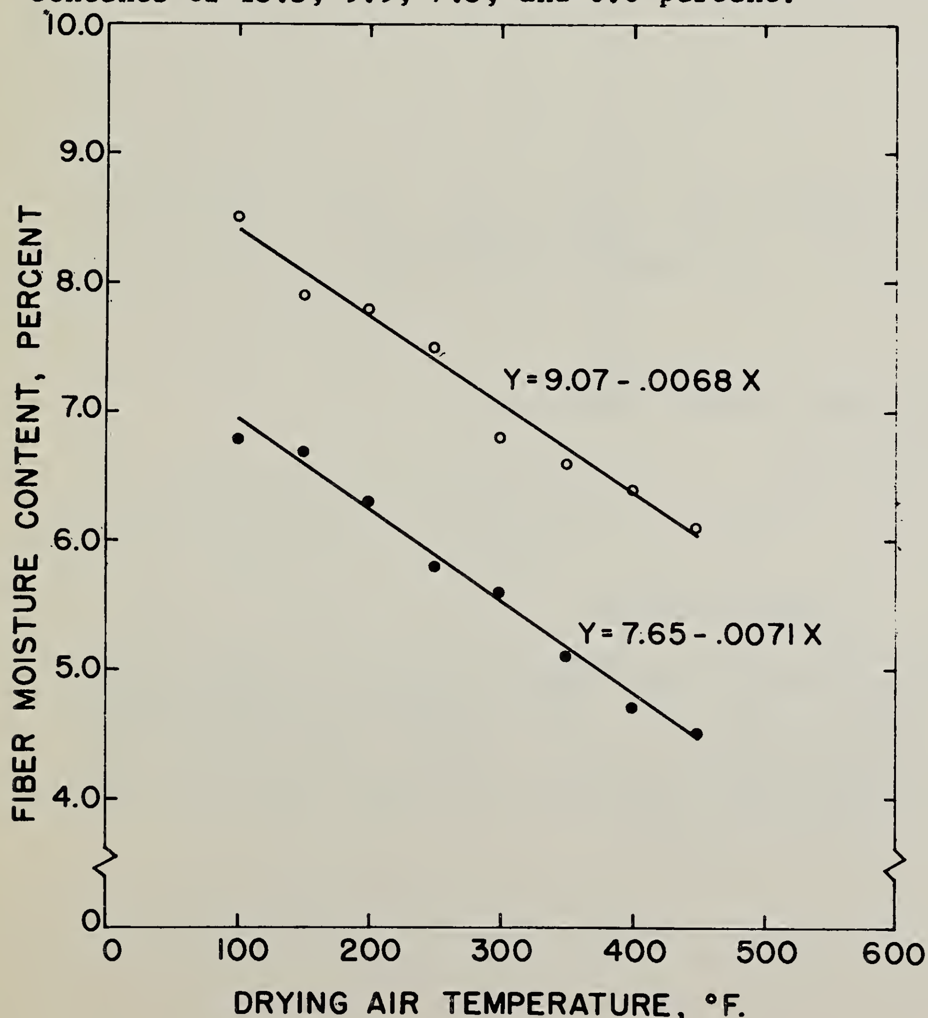

Figure 3. Fiber moisture content after 30-second drying of cotton with initial fiber moisture levels of 7 and 9 percent. Moving bed experimental drier, 1965.

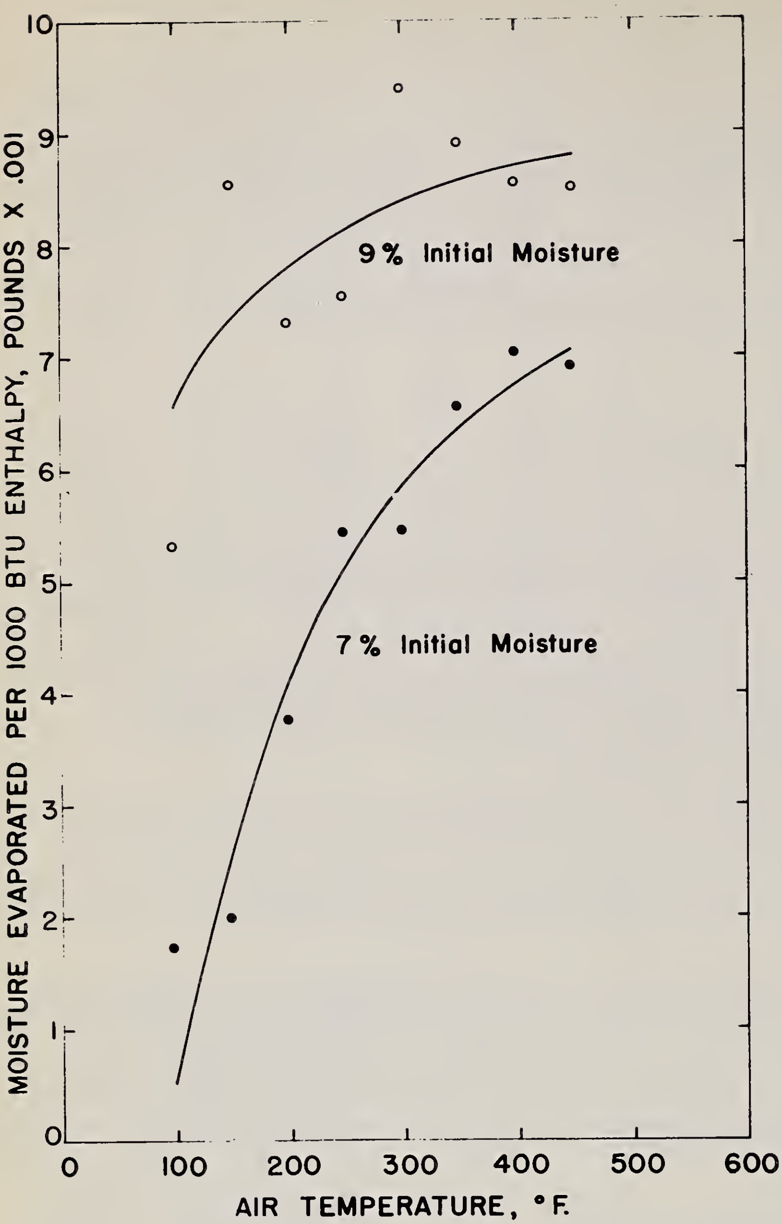

Figure 4. Effect of initial moisture content and air temperature on heat utilization in moving bed drier, 30-second drying period, 1965.

Exposure Time

Exposure time was found to have a logarithmic relation to the moisture content of the fiber after drying (fig. 5). Fiber moisture content versus exposure time produced the regression line log Y = .998 - .111 log X. The decrease in fiber moisture content with increase in exposure time was reflected as a decrease in the heat-utilization factor.

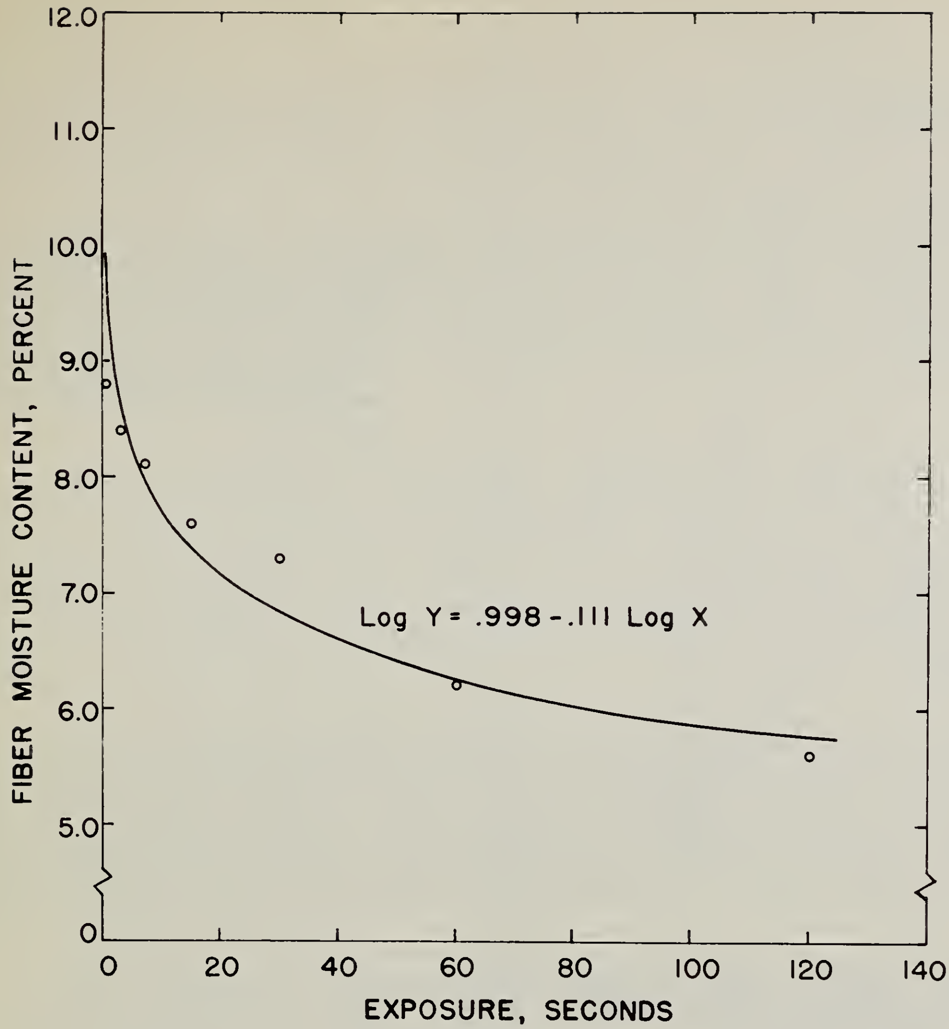

Figure 5. Fiber moisture content versus exposure period. Moving bed drier at 230° F., constant air volume, and air/cotton mass ratio, 1963. Depletion of readily available moisture is responsible for this relationship.

Cotton and Cottonseed Quality

This report is not intended to give a comprehensive analysis of the effect of seed cotton drying on cotton quality; however, cotton quality is too important a subject to be completely ignored. Visual observation during drying showed that lots dried at 400° F. for 30 seconds contained several locks that were slightly tinged, and seed cotton dried at 450° F. contained many locks that were tinged and heavily scorched. Also, exposing seed cotton for 30 seconds to temperature above 300° F. was found to have an adverse affect on seed germination (fig. 6).

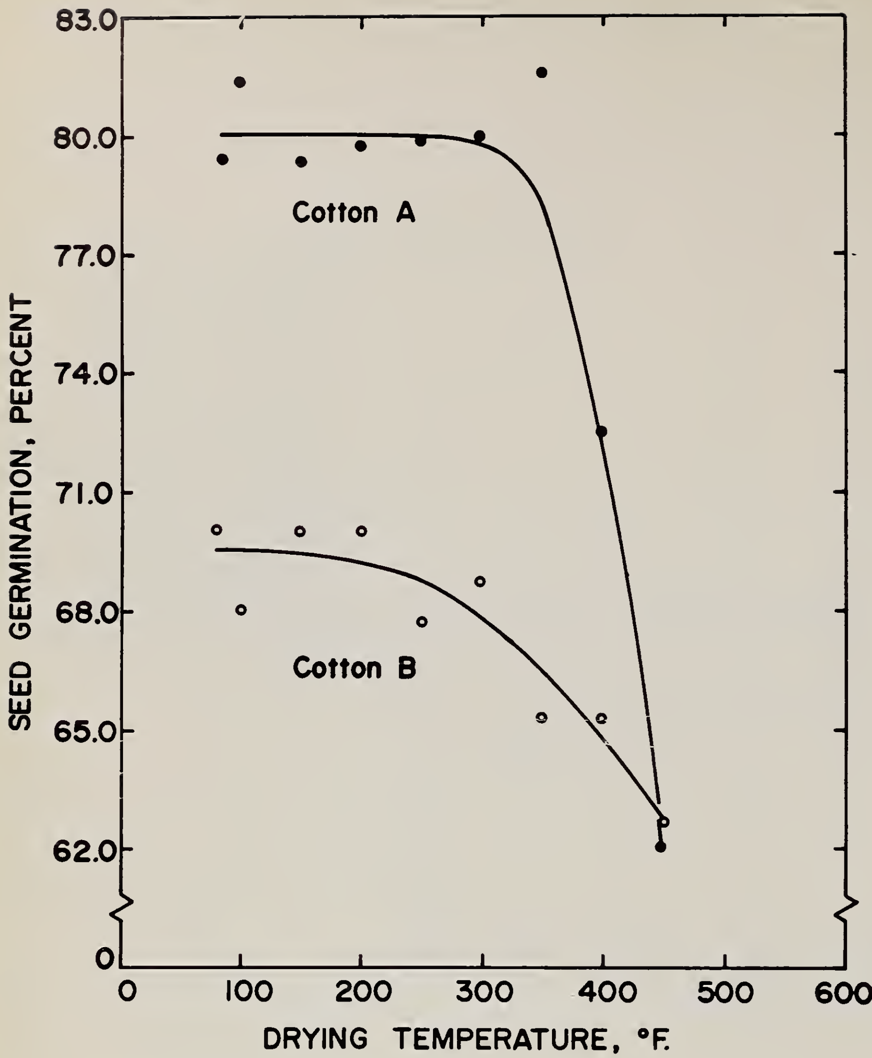

Figure 6. The effect on seed germination of 30-second exposure of seed cotton to temperatures ranging from ambient to 450° F.

COMPARISON EXPERIMENTS, 1966

The experimental moving bed drier was moved into the Laboratory's pilot-sized gin plant for comparison of its moisture-removal efficiency with that of shelf-type driers.

Drier comparisons were obtained from the following drying treatments and process-machinery sequences:

Treatment A. Shelf drier No. 1, shelf drier No. 2, six-cylinder cleaner, stick machine, six-cylinder cleaner, extractor feeder, 20-saw gin stand, and two stages of saw cylinder lint cleaning.

Treatment B. Moving bed experimental drier, six-cylinder cleaner, stick machine, six-cylinder cleaner, extractor-feeder, 20-saw gin stand, and two stages of saw cylinder lint cleaning.

Each drying treatment required twenty 50-pound seed cotton lots, involving initial moisture levels of 10.1, 10.3, 12.7, and 17.7 percent. Ginning rate was 8.3 pounds of seed cotton per minute.

Drying air volume of 717 c.f.m. was constant for both drying treatments, providing an air/cotton mass ratio of 6.5 to 1. Drying exposure period was 20 seconds for all experiments and, for the shelf drier, the mix-point temperature, where initial contact is made between cotton and heated air, was 200° F. Air enthalpy of 316 B.t.u. per pound of seed cotton was maintained for both experimental conditions.

During the study an automatic sequential temperature recorder measured the temperature gradients across both shelf driers. Temperatures measured at the inlet, center, and exit of the driers, and at the air-cotton separation point, averaged 200°, 149°, 111°, and 77° F., respectively. For the moving bed drier treatment the 200° F. air temperature below the batt varied approximately 10 degrees along the cross section with a 40-degree drop across the seed cotton batt.

Lint moisture samples taken between gin stand and first lint cleaner showed that the moving bed drier was less efficient in moisture removal than the shelf-type driers. This finding indicates that the continuous agitation and resultant intimate intermingling of heated air and cotton produced by the shelf drier system more than compensated for the heat losses associated with that system.

Fiber moisture content of the cottons dried with the shelf driers averaged 5.3 percent for the study, whereas the cottons dried with the belt drier gave an average moisture content of 6.0 percent (table 3).

SUMMARY AND CONCLUSIONS

Research at the U.S. Cotton Ginning Research Laboratories led to the design and development of an experimental moving bed drier during the spring and summer of 1963. Airflow was so controlled that during the period when cotton was in the drier, the drying air temperature remained nearly constant from cotton inlet to outlet. Provisions were made for control of air/cotton mass ratio, drying air temperature, and exposure period. The experimental drier proved to be a valuable research tool in the development of data for the several parameters that affect drying processes.

Laboratory experiments conducted during 1963, 1964, and 1965 showed:

1. The higher the initial fiber moisture level, the greater the drier efficiency with respect both to the amount of moisture evaporated and the heat-utilization factor.

Table 3. Fiber moisture content at ginning, drier evaluation study, crop of 1966[1]

Types of drying treatment and replication No.[2]	Trial 1	Trial 2	Trial 3	Trial 4
	Percent	Percent	Percent	Percent
Two shelf driers:				
1	4.3	3.6	8.3	8.1
2	3.9	3.8	6.1	6.3
3	4.2	4.4	6.6	6.2
4	3.2	5.3	6.0	6.4
5	3.4	4.4	4.6	6.7
Average[3]	3.8	4.3	6.3	6.7
Moving bed drier:				
1	4.8	4.2	8.0	8.6
2	4.4	4.6	7.4	8.7
3	4.7	5.0	6.8	7.8
4	4.1	5.9	5.9	7.5
5	4.2	5.9	4.7	7.4
Average[4]	4.4	5.1	6.6	8.0

1/ Date for each replication is an average of three samples taken between gin stand and first lint cleaner.

2/ Both treatments used 717 c.f.m. of heated air with an exposure period of 20 seconds.

3/ The average percent for all four entries is 5.3.

4/ The average percent for all four entries is 6.0.

2. The greatest reduction in drying energy loss was obtained by reducing the air/cotton mass ratio. Decreasing the air volume resulted in increased heat-utilization efficiency.

3. The quantity of moisture evaporated can be best controlled by (a) controlling air temperature, or (b) controlling exposure period.

4. Exposure period showed a logarithmic relationship to final moisture content and to heat utilized, an illustration of the conventional falling-rate drying theory.

5. Within the conditions of the experiments, the efficiency of heat utilization increased as the temperature increased. However, any change that would hasten moisture evaporation would cause the efficiency-temperature curve to peak and turn downward at lower temperature. This is an important relationship for drier operating efficiency.

Comparison experiments in 1966 showed the moving bed drier to be less efficient in moisture removal than the two-tower drying system.

The principal conclusion to be drawn from these experiments is that some agitation--tumbling or stirring--of a seed cotton mass during drying provides more rapid and more uniform drying than that provided by heated air moving through an unagitated bed of cotton where new surfaces are not continuously exposed by the tumbling action. Similarly, flat bed units for moisture restoration are not likely to be as efficient as a resotration system that provides for tumbling.